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DSO-TSO Interactions in Flexibility Contracting

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SUMMARY

Consumer empowerment drives changes in the distribution grid. Users can decide to install solar power, smart appliances, storage and electric vehicles. They now have the capability to output power into the grid and modify their consumption profiles if they wish to do so. Distributed generation is increasing leading toward a decentralization of the power system. At the same time, these variable renewable energy resources installed in the distribution grid cause hard to predict variations in the supply profile. Distribution grid operators are challenged to manage these changes.

The effective management of the new decentralized grids requires close cooperation between distribution and transmission system operators. This paper examines cooperation models between DSOs and TSOs which could be best suited to enable the use flexibility resources located in the distribution system. Two conceptual models for flexibility contracting have been identified in literature. The first conceptual model is DSO-centered approach where the DSO contracts flexibility to be used for grid purposes directly from the flexibility service providers (FSPs). This flexibility can later be used for the DSO's own grid needs, re-sold to the TSO or to a third party that may need it. The second conceptual model is a TSO-centered approach where the TSO is the first one to have access to all flexibility resources, including those in the distribution grid. A case study for each model is presented, the FLECH market proposal in Denmark represents a DSO-centered approach to flexibility contracting; while the Bid-Ladder proposal in Belgium presents a TSO-centered approach to flexibility contracting.

The expected costs and benefits of contracting flexibility are then outlined. It is expected that flexibility contracting can help to diminish losses, renewable energy curtailment, and investments in grid reinforcements. Flexibility also represents costs of reservation and activation of the flexible resources, risk of non-compliance and added transaction costs. Each of the presented models is qualitatively evaluated in terms of expected costs to determine trade-offs of each alternative.

It is concluded that the main benefits of a DSO-centered model are: avoiding double booking of resources, enabling visibility of flexibility to the DSO at all times, and promoting local grid management. The downside of this model is that it creates transaction costs for the DSO in case that he doesn't need to use the pre-contracted flexibility resources. Also, this model implies that a priority is given to the DSO in the use of flexibility, which might not always be necessary. In contrast it is argued that a TSO-centered model is a fair approach since the TSO holds the responsibility for balancing the system as a whole and has a more thorough vision of the overall grid conditions. The downside of this approach is that the distribution grid criteria is not taken into account as it implies that the TSO is contracting and then activating flexibility resources in the distribution network, without having visibility of that particular network. It is foreseen that there is no one-size-fits-all solution, but rather a combination depending on the conditions of a particular network, and relationship between the involved stakeholders.

KEYWORDS

Flexibility Contracting, Demand Response, Distribution System Operator, Transmission System Operator, Distributed Generation, Distributed Renewable Energy Sources

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1 INTRODUCTION

Power systems are changing due to the introduction of variable renewable energy sources (RES) and distributed generation (DG). Distributed generation is leading the system towards a decentralization of the power system. Grid operators are challenged to cope with these changes as networks were built considering that energy would flow from the high to the mid and low voltages, and not vice versa. The effective management of the new decentralized grids requires close cooperation between distribution and transmission system operators. Distributed generation is defined as electric power generation within distribution networks or on the customer side of the network [1]. The benefits of DG include improved security of supply, improved demand-response capabilities, better peak load management, reduction of grid losses and network infrastructure cost deferral according to the authors in [11]. Better coordination between system operators can improve the use of flexibility services located in distribution grids. Challenges to the integration of DG are classified as technical, commercial and regulatory [10]. Technical challenges are voltage rise effect, power quality (transient voltage variations, harmonic distortion of the network voltage), protection and network stability. Commercial challenges are cost recovery, incentives for private DG investment, and the establishment of a market mechanism for active networks where DSOs offer active management services to generators for a charge. From a regulatory perspective clear policy and regulatory instruments are needed. DG management services should be able to provide capability of aggregation of hourly DG production levels and forecasting, limit production injections in the transmission grid through local DG control; limit DG ramping rates; manage reactive power support; and manage active power reserves. A report by ISGAN [8] states that congestion of the transmission-distribution interfaces and the balancing challenge are, among others, the main discussion topics of interaction between DSOs and TSOs. The report also highlights the importance of the role of markets and regulation in reaching adequate solutions for cooperation. In terms of the role of markets ISGAN proposes to use market mechanisms only for the balancing challenge.

This paper seeks to examine cooperation models between DSOs and TSOs which could be best suited to enable the use of flexibility resources located in the distribution grid for the benefit of the whole system. The first conceptual model is a DSO-centered approach one where the DSO contracts flexibility to be used for grid purposes directly from the flexibility service providers (FSPs). This flexibility can later be used for the DSO's own grid needs, re-sold to the TSO or to a third party that may need it. In the second conceptual model the TSO is the first one to have access to all flexibility resources, including those in the distribution grid. A case study of each approach is presented and the trade offs are conceptually evaluated through the possible costs and benefits of each approach.

Current discussions on the topic of DSO-TSO cooperation with respect to flexibility contracting are presented in section 2. Literature supporting DSO or TSO priority in flexibility contracting is presented in sections 2.1 and 2.2 respectively. A DSO-centered case study of the FLECH market proposal in Denmark is presented in section 3. A TSO-centered case study of the Bid Ladder proposal in Belgium is presented in section 4. Section 5 presents the expected trade offs in costs between the different cooperation models. Finally section 6 presents conclusions and further research suggestions.

2 CURRENT DISCUSIONS DSO-TSO COOPERATION

There are two main approaches in the literature regarding the interaction between system operators when it comes to flexibility contracting. The main differences in approach in the literature stem from who should have the first priority when it comes to contracting flexibility located in the distribution grid. One trend places the DSO as an active system manager who has first priority over the resources connected to it's grid. The other trend gives priority to the TSO in contracting all flexibility resources on both the TSO and the DSO grid since the TSO has the responsibility to maintain the integrity of the entire system. Figure 1 presents a visual simplification of the proposed approaches for flexibility contracting and the interaction of the DSO and TSO in each one.

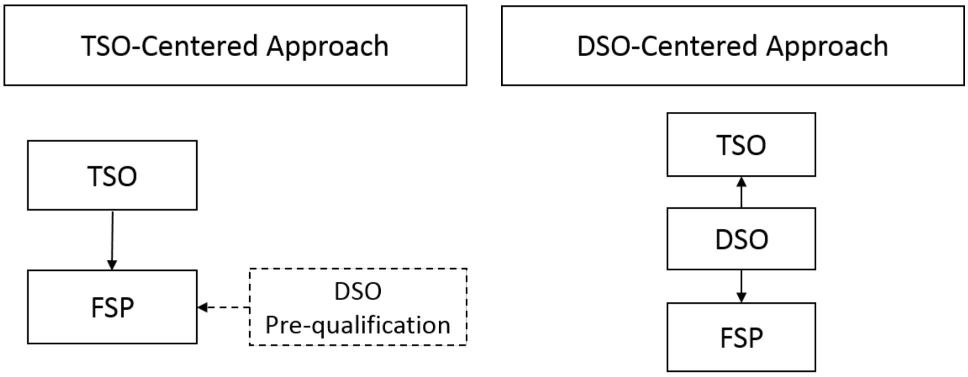

Figure 1: Proposed Approaches in Flexibility Contracting

2.1 DSO PRIORITY IN FLEXIBILITY CONTRACTING

In this scheme the DSO acts as an active system manager and contracts flexibility services to fill balancing needs and manage congestion in the network. In these type of proposals the DSO will directly contract flexibility resources and have priority over their use.

The authors in [19] introduce the notion of a hierarchical market where a restriction is made to trade resources first at a local level and second at a wider grid level in the absence of congestion. EDSO highlights the need for increased DSO-TSO cooperation [6]. They state that DSOs are responsible for the security and quality of supply of their own networks. As such, DSOs should collect the data of the customers connected to their networks. Other system operators, such as the TSO, should not interact with customers connected to DSO networks. EDSO supports a model based on the concept of 'cascading responsibilities' where each system operator is responsible for its own grid and grid users. Data needs for each system operator should be defined. System planning should be coordinated between the TSO and DSO. Connection requirements for grid users should be defined by both DSOs and TSOs together. To facilitate the integration of RES, TSOs and DSOs should regularly exchange and publish information regarding their available network capacity at the TSO/DSO interface. DSOs will need to procure system flexibility services and oversee their effects on the grid. The report also states that electricity markets will have to evolve to take into account distribution networks and the location of generators and service providers. DSOs will have to validate the technical availability of flexible resources connected to its network in three stages: pre-qualification of the flexible resource (in terms of potential constraints on the distribution network), activation of the resource, control of energy effectively consumed or produced.

The European FP7 project EvolvDSO proposes a new role for DSOs as a 'distribution constraints market officer' [13] [15] [16]. The DSO would have the capability to contract and activate flexibility on different timeframes. The project proposes the need to contract flexibility in the long term to achieve grid reinforcement deferral, non-firm grid connection and access contracts allowing temporary limitations on feed-in or power consumption, and real time flexibility contracting for operational management. The operational market would need to have strong coordination with the TSO and other existing markets. Similarly, the role of the DSO as neutral market facilitator is highlighted as the DSO should be involved in pre-qualification, validation of bid activation and settlement procedures of market operations. In terms of communication with TSOs the report stresses the need for exchange of structural and operational information. DSOs will need to manage TSO requests at different timeframes including network development, forecasting, operational planning and real-time operations. It is also estimated that the DSO can provide regulated services to the TSO through a cascading communication process. In [14] it is recommended to establish a hierarchy between TSOs and DSOs regarding flexibility contracting, as well as cascading processes for system support and operation.

The DSO-TSO interaction has been studied in Portugal in [17]. The paper studies the impact of DG on distribution networks regarding losses, voltage profile, system stability, network capacity and congestions, system balancing and reserve, short-circuit level, protection selectivity, network robustness and power quality. The authors state that DG connection might lead to change or distortion of the voltage profiles at transmission nodes. In [3] it is stated that as interaction with the TSO increases real time information capabilities will allow the DSO to perform real-time analysis of the power flow and state of the distribution grid. The information retrieved would include active power, reactive power, voltage measurement levels and remote automation device states. This enables the increase of distributed generation penetration. The authors in [3] study the case of a DSO in the Netherlands with a large amount of CHP plant connection. Due to the regulation, the DSO must connect CHP plants faster than they can reinforce the network. The introduction of DG also causes congestion in the local transmission grid, which would also need to be reinforced. The authors propose a coordinated DSO-TSO proactive planning approach. One of the possible solutions presented is the elimination or deferral of the construction of a TSO-substation by connecting DG to the local MV-grid and accepting bi-directional power flows. This option requires investments in connection rather than in substations. These solutions are restricted by fault level, protection issues and power quality.

The European research project ADDRESS proposes a flexibility architecture where the aggregation function is provided by the retailer. The project describes the TSO and DSO as flexibility buyers and technical verifiers of flexibility services [2], [12]. They propose two options to do the technical verification: 'ex-ante' before the activation of consumers by aggregators, or in 'real time' after the market closure. Consumers providing flexibility are grouped into load areas defined by the DSO and TSO. Flexibility programmes are submitted to the system operators. A flexibility table is calculated and published before the market opening to allow participant bid creation. In a follow up publication of the same project the DSO functional architecture is divided into three control levels: a central control, an HV/MV substation level for MV network monitoring and an MV/LV substation level for LV monitoring [18]. The DSO and TSO are asked to provide information on the location of consumers providing flexibility and on whether flexibility actions comply with network constraints. In order to achieve this the project proposes an active demand management system.

2.2 TSO PRIORITY IN FLEXIBILITY CONTRACTING

In this scheme the TSO is in charge of contracting flexibility resources directly, even when resources are located in the distribution network. The DSO has a passive role in ex-ante pre-qualification of flexibility resources. The DSO could determine a one-time worst-case scenario and set a thresh hold accordingly, or do periodic checks of the effect of flexibility resources located in the distribution network.

ENTSO-E identifies needed changes in the TSO-DSO interface in order to unlock consumers' potential as electricity producers and balancing actors [5]. The report highlights the need for DSOs and TSOs to support a market framework that unlocks the flexibility potential of consumers, and consumers should have access to participate in all markets. Also, TSOs and DSOs should work together to determine requirements for observability and active power management of DG and DSR. They state that the fragmentation of markets should be avoided, and it is preferable to have a unique marketplace for both flexibility and balancing. The report also recommends that DSOs cannot be on both sides of the market as both market facilitator and service provider; if they need a system service they cannot be buyer and provider at the same time. Balancing markets should evolve to take into account and deal with operational constraints of TSOs and DSOs. In terms of operational interaction the report states that TSOs will continue to have the leading responsibility for balancing, frequency control and system restoration, whereas DSOs will maintain their responsibility for managing their network, with an increasing need to manage distribution congestion and voltage. The report places the emphasis on operation and control on the TSO, even for resources connected to the distribution network:

- All active power management actions with an impact on system balancing and/or the transmission system should be overseen by the TSO and implemented either directly by the TSO, through the DSO or aggregator.
- TSOs and DSOs should cooperate on the definition of controllability procedures on DG and DSR resources and especially to find the solution to allow TSOs to curtail DG or activate DSR, wherever

its connection point, in alert and emergency system states.

- It is necessary to define an efficient operational procedure when: (i) both networks are affected by congestions (i.e. who acts first, who pays, etc.), (ii) TSO balancing actions have an impact on DSOs, and (iii) DSO congestion management actions have the potential to affect the TSO network.

The Florence School of Regulation [7] recognizes that in a scenario of high decarbonization more decentralized resources are expected to develop, and it will be necessary for the DSO and TSO to cooperate. The report identifies balancing decisions in one network that could affect the other network. They propose that congestion management decisions at distribution level should be neutral for the transmission system or should have to pay an imbalance fee. Similarly, decentralized resources used for managing the transmission system should consider their declared price in the balancing market as well as their shadow cost for the distribution system. The report envisages three solutions: a. DSOs operate their system according to the format of their respective TSOs. b. The transmission system operator expands its operation to the distribution system. c. TSOs and DSOs share a security cooperation initiative. Market rules should adapt to the new resources while allowing aggregator participation. The authors in the report expect new transmission tariffs for generators related to locational incentives. Consumer tariffs would need to be updated to reflect this change.

In [9] the need for transmission grid interfaces with distributed resources is described through the use of smart substations that incorporate microgrids and can operate in islanding mode.

3 CASE STUDY: FLECH MARKET - A DSO CENTERED MODEL

The FLECH market is a flexibility clearing house proposed to accommodate small scale distributed resources [20] [4]. The purpose of this clearing house is congestion management in the distribution grid. The main two purposes of this market are feeder overload management and feeder voltage management. Two main setups are proposed:

- Single-side aggregator auctions: where the DSO proposes a request for flexibility and aggregators submit orders to satisfy the DSO needs. In this setup the DSO decides whether it is best to buy flexibility services or invest in new grid reinforcements.

- Super market: in this setup the aggregators have the initiative, they propose various services and the DSO as a buyer chooses according to its needs. Here the aggregator optimizes a portfolio of flexibility resources seeking to minimize costs.

- Products for load management:

  – Planned powercut: based on forecast of available network capacity.
  – Urgent powercut based on events instead of forecasting.
  – Power Reserve: through this product DSOs can allow the loading of 10kV feeders to exceed beyond 70% capacity limit but still below 100% capacity limit.
  – Powercap: ensure that a capacity limit specified by the DSO will not be violated.
  – Powermax: similar to powercap, but it ensures that the aggregator's local portfolio will not exceed a certain amount of power during the activation periods.

- Products for voltage management:

  – Voltage Support: the DSO sends a signal to the aggregator specifying the current voltage deviation in the network. The aggregator modifies settings of the load to comply with the DSO requirement.
  – Var Support: distributed generation units with the capability to modify their reactive power output can offer VAr support to the DSO.

- Pricing: depending on the type of product the pricing can have either of an availability payment, an energy activation payment or both. Penalties also apply in case of defaults.
- Congestion Management: products are requested for specific geographic areas and connection points according to specifications of the DSO.
- Flexibility type: both load and distributed generation qualify. Load must participate through an aggregator.

The FLECH market is a DSO-led market that serves to optimally operate the distribution grid and enable the integration of DRES. The effect of the DSO actions on the TSO network is not directly taken into account.

4 CASE STUDY: BID LADDER - A TSO CENTERED MODEL

The Bid Ladder, a project proposed by the Belgian TSO, is a platform where market players can bid their available flexibility. It will allow bids from load and RES flexibility, as well as resources connected to the distribution grid. The platform would be oriented towards tertiary or manual frequency restoration reserves. Within the tertiary reserves the TSO defines two categories: pre-contracted reserves or ancillary services that receive a capacity payment, and non-contracted reserves or bids. These last are the focus of the bid ladder, that is to say, reserves that don't receive a capacity fee and only the residual remaining flexibility is offered in the balancing market.

- Products: Three types of balancing energy products will be allowed in the bid ladder platform:
  - A fast standard product: has a 15 minute activation time and is activated at the moment of request without delay.
  - Slow standard product: has different activation durations -15, 30, 45 minutes- and a 15 minute activation delay.
  - Emergency products: the remaining flexibility of power units with installed capacity bigger than 75 MW is offered to Elia. This flexibility is to be used in case where reserves cannot be offered through the standard products and in case of exceptional circumstances.

  The total activation time of the standard products is up to one hour.
- Price:
  - Activation price: in case of a positive price the provider receives money for an upwards activation and needs to pay money for a downwards activation. In case of a negative price the provider pays money for an upward activation and receives money for a downwards activation.
  - Prolongation price: when the TSO requests the activation of a bid that was already activated in the current time frame, a prolongation price can be paid.
- Congestion management: locational information of each resource must be provided for units larger than 25MW in the first stage of the project. In case of smaller units, the required information will need to be discussed with the DSO.
- Flexibility type: a bid for flexibility can be provided by generation, load or both.
- Technical prequalification: units above 25 MW will be pre-qualified individually; while smaller units may be aggregated. In order to qualify bids should be based on physical regulation, the requested delivery should be maintained at a stable power level, once the delivery of the bid is finished the physical regulation used should be able to go back to its normal level within 15 minutes.

The bid ladder is a TSO-led model where the TSO takes the decision of what flexibility will be contracted. The DSO has the role of pre-qualifying resources through a worst case scenario check, but is not active during operation and does not decide what flexibility resources could or should be deployed.

5 COSTS AND TRADE-OFFS

The ideal market configuration from a social welfare perspective would be the one that increases social revenue and minimizes overall system costs. In order to qualitatively evaluate the trade offs of each model a series of indicators shown in equation 1 need to be taken into account.

$$\min\{C^{L} + C^{Curt} + C^{rflex} + C^{aflex} + C^{risk} + C^{trans} + C^{inv}\} \quad (1)$$

The cost of grid losses is represented by C^{L} in [€/MWh]. It can be estimated that under a DSO centered approach losses will decrease more than in a TSO centered approach since most losses occur in the distribution netowrk. The cost of curtailing distributed RES due to grid congestion or demand variations in [€/MWh] is represented by C^{Curt}. In a DSO centered approach there is a better chance to manage local congestion and therefore the expected curtailment cost would be lower than in a TSO centered approach. The aggregator will receive C^{rflex} and C^{aflex} which represent the cost of reservation and activation of flexibility respectively in [€/MWh]. This cost will depend on the price setting mechanisms used, and the deployment of flexibility will also depend on grid conditions. It is estimated that for the DSO it is only worth it to pay this cost if it is less than the investment cost in network reinforcements C^{inv}. For the TSO however there might be a higher threshhold if flexibility from the distribution network can prevent the use of other more expensive reserves or peaking emergency units. Transaction costs are represented by C^{trans}, and include concepts such as contracting and management costs of flexibility provision [€]. Due to the large volume of consumers in the DSO grid, under a DSO centered approach transaction costs are expected to be higher than on a TSO managed grid. Grid investment is represented by C^{inv} in [€/MW]. The cost for grid investment is expected to be lower on a DSO centered approach where the grid will be micromanaged so that the limits will be maintained. Table I summarizes and compares the expected cost reductions with a minus (-) sign for a small cost reduction, double minus sign (- -) for bigger expected cost reduction, and a plus (+) or double plus (++) for expected cost increases under each approach.

Estimated trends for each concept are presented below in table

Cost Concept	**DSO Centered Approach**	**TSO Centered Approach**
Grid Losses	- -	-
DRES Curtailment	- -	-
Flexibility Cost	-	- -
Transaction Costs	++	+
Risk Premium	++	+
Grid Investment Costs	- -	-

Table I: Flexibility Approach Contracting Trade-Offs

6 CONCLUSION

In the first conceptual model the DSO contracts flexibility to be used for grid purposes directly from the flexibility service providers (FSPs). This flexibility can later be used for the DSO's own grid needs, re-sold to the TSO or to a third party that may need it. The main benefits of a DSO-centered model are: avoiding double booking of resources, enabling visibility of flexibility to the DSO at all times, and promoting local grid management. The downside of this model is that it creates transaction costs for the DSO in case that it doesn't need to use the pre-contracted flexibility resources. Also, this model implies that a priority is given to the DSO in the use of flexibility, which might not always be necessary.

The second conceptual model is a similar derivation where the TSO is the first one to have the one access to all flexibility resources, including those in the distribution grid. It can be argued that this is a fair approach since the TSO holds the responsibility for balancing the system as a whole and has a more thorough vision. In an opposite view, it implies that the TSO is contracting and then activating flexibility resources in the distribution network, without having visibility of that particular network. A clear division of responsibilities and communication protocols is necessary for this model to work.

Further empirical research is needed to assess the benefits of each possible approach for a given power system. The optimal solution will depend on the topology of the system, the amount of DRES connected to a distribution grid, and the available flexibility resources. Other solutions, such as the introduction of an independent location-specific flexibility market could also be proposed. The introduction of more DRES, storage and electric vehicles in the future will cause need for an increase in DSO-TSO cooperation in terms of contracting, information sharing, and operation.

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